Meltwater feedbacks and acceleration of sea-level rise: likely in Greenland, possible in WAIS?

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Background

- Classic story of Greenland Ice Sheet (GIS):
  - ⋆ Little or no sliding
  - ⋆ Slow melt if too-much warming
  - ⋆ Inherent stability wrt “rapid” climate fluctuations offered by long glaciological timescales in GIS setting

Background cont'd

- But, new Swiss-Camp study... (Zwally et al., 2002):
  - ⋆ Surface melt in summer $\leadsto$ faster flow
  - ⋆ More melt $\leadsto$ even faster flow
  - ⋆ Sliding matters

Hypothesis

Future warming $\rightsquigarrow$

more surface melt $\rightsquigarrow$

faster flow $\rightsquigarrow$

more sea-level rise

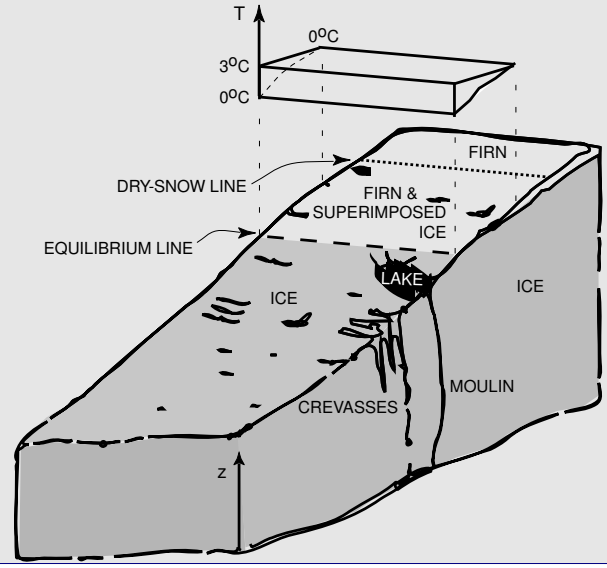
New sliding law

- Fit Zwally et al.'s data
- Annually averaged
- Linear in stress

$$u|_{z=b} = C(1 + \bar{\mathcal{Z}}\mathcal{Q})\tau_b$$

no surface melt, some sliding if bed is thawed

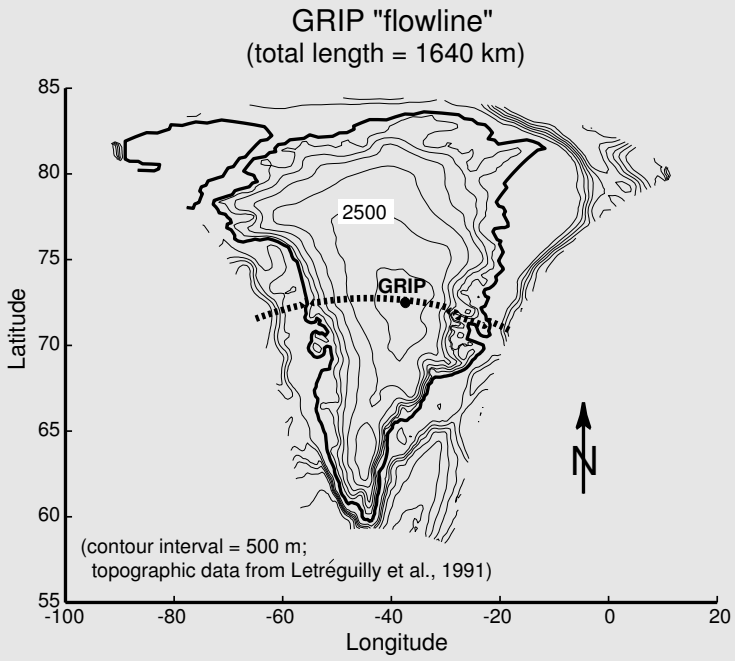
more surface melting, more sliding

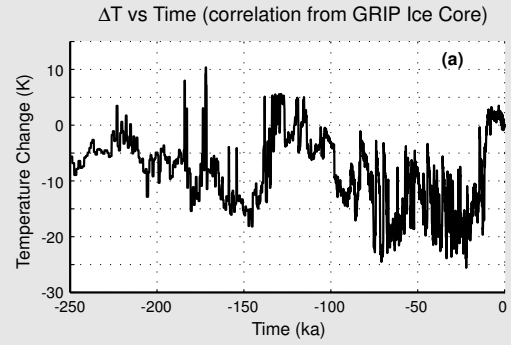


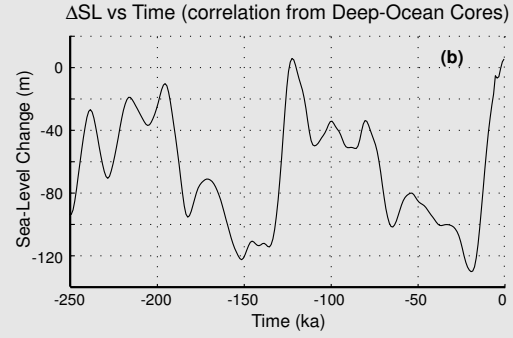
The PSU/UofC Flowline Model

- Fast
- Thermomechanical
- Well-characterized FEM techniques (MacAyeal)
- Good isostasy (ELRA; Le Meur and Huybrechts, 1996)
- Good firn and superimposed ice
- Degree-day surface melt (Braithwaite and Thomsen, 1984)
- Benchmarked vs EISMINT, compares well

Experiments







- Calculate steady Greenland cross-section
- Force with 250 ka of Δclimate and Δsea level
- Last 15ka, try many variants of Zwally sliding

Variants on Zwally sliding

- If melting moves inland with warming
  - –does all the extra water reach bed?
  - $\star\star$does the point where it reaches bed move inland?
- How warm? 2XCO_2, 4XCO_2, 8XCO_2?
- Slipper Zwally, average Zwally, sticky Zwally fits to data

Total of 84 tests!

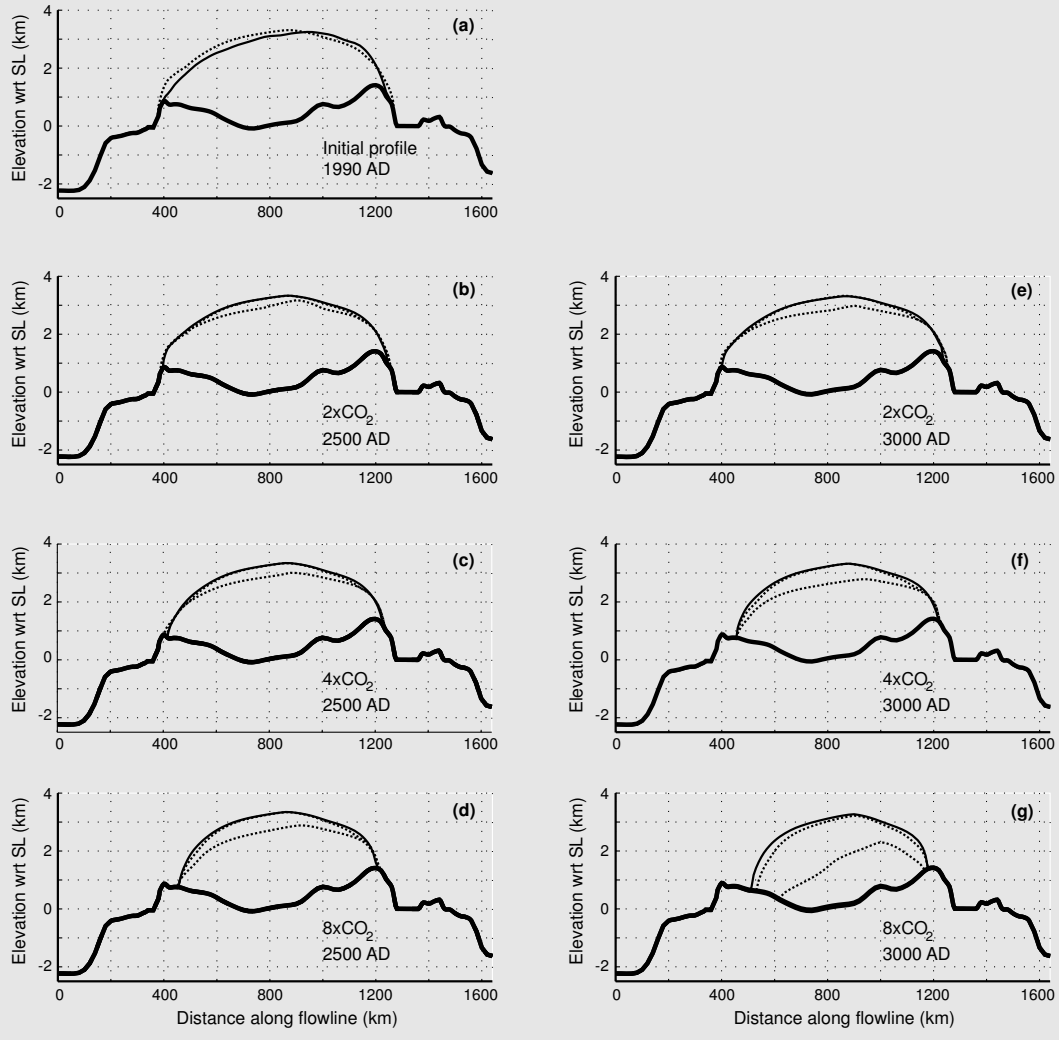
What do we find?

In 2500 AD:

	Huybrechts and de Wolde (1999)	How much more sea-level rise we get with Zwally than without*	
	approx. (cm)	our favorite (cm)	our range (cm)
2X	40	15	15–108
4X	150	22	15–154
8X	320	40	31–262

*using shape factor

Pretty pictures



So why am I at WAIS?

- WAIS isn't that far from summer melt
- Melt gets through $>$1220 m of Greenland ice
- Zwallyization of WAIS may not be as far away as we would like
- Looking at WAIS future melt may be wise

Conclusions

- Rising surface temperatures will lead to increased surface melt in the ablation zone.
- Increased sfc. melt $\rightsquigarrow$ increased ice velocities in the ablation zone $\rightsquigarrow$ increased ice flux from the accumulation zone into the ablation zone
- Rising surface temperatures and a falling ice surface $\rightsquigarrow$ inland migration of dry-snow line $\rightsquigarrow$ progressively involvement of a greater percentage of the ice sheet in this rapid response mode of ice dynamics
- Zwally-based meltwater-enhanced sliding increases modeled GIS sensitivity to warming

Conclusions cont'd

- Important to understand water access to bed & how might change in future
- IPCC sea-level rise estimates may be low
  (an additional $\sim$15-40 cm by 2500 AD is conservative)
- If WAIS warming large, this effect may move South...